LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA16 | Ladbroke and Southam

Ladbroke to Southam river modelling report (WR-004-009)

Water resources

November 2013

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Appendix WR-004-009

Environmental topic:	Water resources and flood risk assessment	WR
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Community forum area:	Ladbroke and Southam	016

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1 Overarching modelling approach

1.1 Introduction

1.1.1 This section of the Proposed Scheme crosses numerous watercourses with the potential to affect flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of proposed culvert and viaduct structures. Therefore, the primary objective of this assessment was to assess the impact of the Proposed Scheme on river flood risk.

1.1.2 The outcome of this assessment will aid the design team to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by this section of the Proposed Scheme. These watercourses were grouped into seven community forum areas (CFA) in this section of the Proposed Scheme. Existing hydraulic models of the watercourses have been utilised where available and new river models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling annex form the basis of the river flood risk in the flood risk assessment (FRA) for CFA16-Ladbroke to Southam (WR-003-016). These conclusions are also reported within the water resources and flood risk assessment (Volume2, Section 13).

1.1.5 Unless otherwise stated maps referred to within this report can be found in Volume 5: Map Book – Water resources.

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this study to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

[1] Centre for Ecology and Hydrology (2009), *FEH CD-ROM Version 3*, *©NERC (CEH).*
[2] Centre for Ecology & Hydrology (1999), *Flood Estimation Handbook – Volume 5: Catchment Descriptors.*

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance, the ReFH method is deemed acceptable for the majority of catchments along the route and is the most time efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines 2012[4], an alternative method was required. Therefore at these locations, the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses that will be crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flows rates, along with a 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 5 (20%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20%.

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one dimension or two dimensions.

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses

[3] Centre for Ecology & Hydrology (2007), *The revitalised FSR/FEH rainfall-run-off method: Supplementary Report No. 1*.
[4] Environment Agency (2012), *Flood estimation guidelines (197_08)*.

with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was adopted; and
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional-two dimensional combination modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard modelling packages have been utilised as part of this assessment: ISIS (version 3.6) and TUFLOW (version 2012). ISIS is software developed by Halcrow mainly used for one dimensional hydraulic modelling of river flooding. TUFLOW is software developed by BMT WBM[6] for two dimensional hydraulic modelling of river, estuarine and coastal flooding.

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of any watercourses crossing the route.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the Proposed Scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Some of the models were run for the 1 in 20 (5%) annual probability where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and proposed scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for

[5] Environment Agency (August 2009), *'Requirements for completing computer river modelling for flood risk assessments – Guidance for developers' Version 3.0.*
[6] BMT WBM (2010), *TUFLOW User Manual.*

climate change flood extents, defined the type of structure to be used at the crossings (i.e. culvert or viaduct) and its dimensions. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to Section of the Flood Risk Assessment WR-003-016).

Input data

1.3.11 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as fine as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for suitability in two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from this DTM.

1.3.12 For existing models, the floodplain topography was updated with this DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.13 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 3 of this report.

1.3.14 The data for the Proposed Scheme model scenario was taken from the scheme design drawings.

One dimensional modelling

1.3.15 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning's roughness parameter. The Manning's roughness values were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.16 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: a minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that would need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culvert were based on the width of the route crossings as defined in the Proposed Scheme design.

Two dimensional modelling

1.3.17 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.18 It should be noted that components within a two dimensional TUFLOW model such as SXZ, HX, Z-polygon, Z-Shape polygons, etc., are based on naming conventions as defined in the TUFLOW manual[6].

1.3.19 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.20 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.21 The Proposed Scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.22 Viaduct structures have been modelled by adding route embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as flow constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to Section 3 of the Flood Risk Assessment WR-003-016).

1.3.23 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimensional domain with a SXZ point link; a GIS point used in the modelling software for one dimensional-two dimensional linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

One dimensional-two dimensional linked modelling

1.3.24 In certain cases where an existing one dimensional model was not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimension and the floodplain component in two dimensions. These models were built using ISIS-TUFLOW.

1.3.25 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer (HX layer), the spill levels of which are defined by the channel bank levels or DTM levels.

1.3.26 In the proposed scheme scenarios, the viaduct structures are represented as discussed earlier in the two dimensional modelling section (Section 1.3.22 of this report).

Sensitivity assessments

1.3.27 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.28 Sensitivity assessment on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and post scheme scenarios, unless stated otherwise.

1.3.29 Sensitivity assessment has also been carried out on Proposed Scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries and descriptors as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow at catchments classed as highly permeable.

1.4.4 The area scaling method, which is based on area, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 1.2 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been adopted for the 1 in 100 (1%) annual probability with an allowance for climate change event.

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the watercourse geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell resolution of the two dimensional model. Therefore, the watercourse geometry is not

well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There were certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. OS Mapping and aerial photography were used to assess the location of the structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the Proposed Scheme for models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

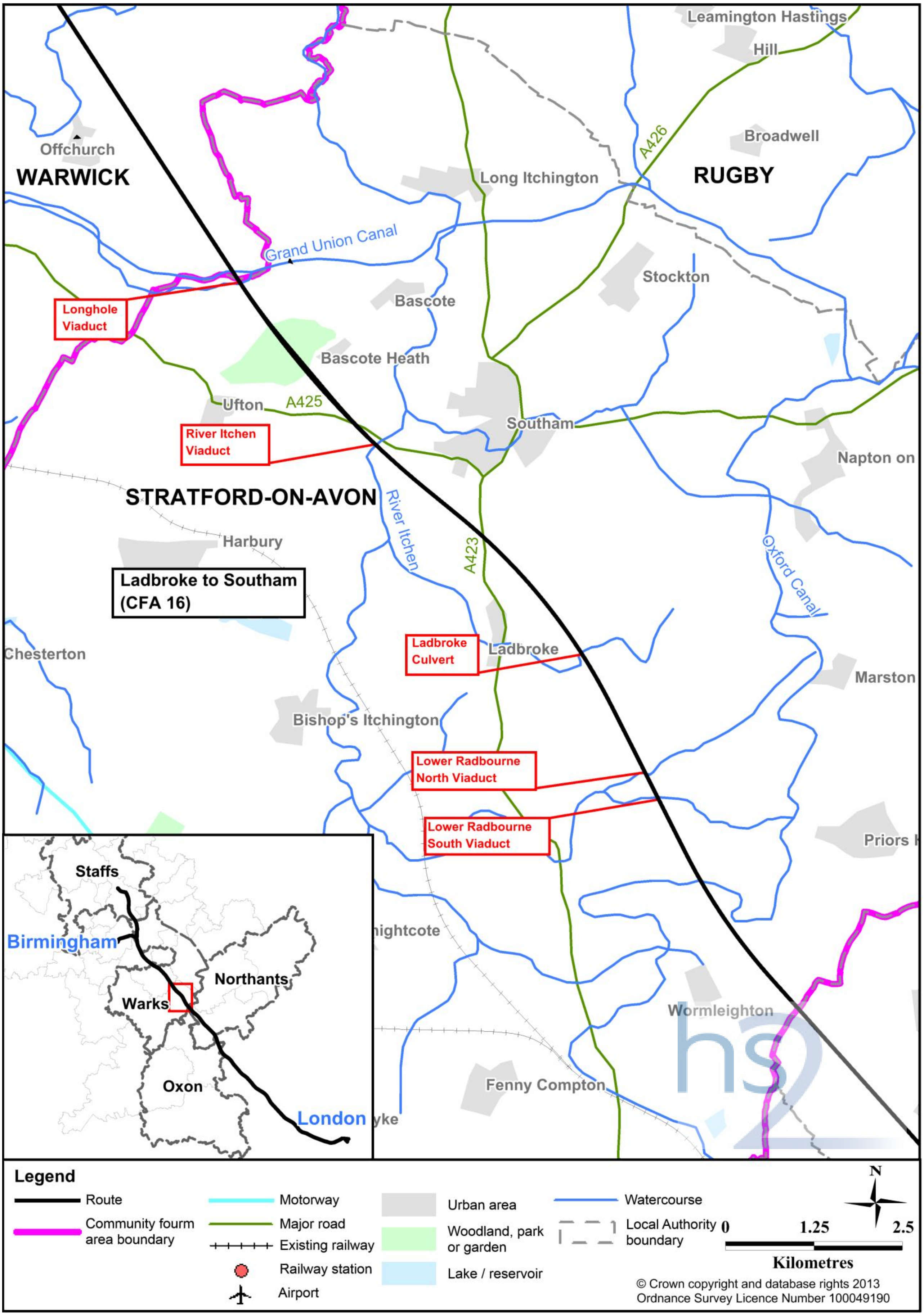
2.1.1 River modelling undertaken at the various watercourse crossings for this study area are summarised in Table 1, along with the modelling methodologies adopted. Figure 1 identifies the location of each of these structures.

Table 1: River models at watercourse crossings

Crossing name	Watercourse identifier and map reference	Watercourse	Hydrology	Hydraulic modelling
Lower Radbourne south viaduct	SWC-CFA16-002 Volume 5: Map WR-05-041, F6	Ordinary watercourse (tributary of the River Itchen)	ReFH	Two dimensional hydrodynamic
Lower Radbourne north viaduct	SWC-CFA16-003 Volume 5: Map WR-05-041, E6	Ordinary watercourse (tributary of the River Itchen)	ReFH	Two dimensional hydrodynamic
Ladbroke culvert	SWC-CFA16-004 Volume 5: Map WR-05-042, H6	Ordinary watercourse (tributary of the River Itchen)	ReFH hydrograph scaled to FEH Statistical estimate from River Leam Hazard Mapping Study	One dimensional steady state
River Itchen viaduct	SWC-CFA16-005 Volume 5: Map WR-05-043, E7	Non-main river (River Itchen)	ReFH hydrograph scaled to FEH Statistical estimate from River Leam Hazard Mapping Study	Two dimensional hydrodynamic
Longhole viaduct	SWC-CFA16-006 Volume 5: Map WR-05-044a, E6	Ordinary watercourse (tributary of the River Leam)	ReFH	Two dimensional hydrodynamic

2.1.2 A summary of the modelling for Ladbroke culvert is provided in Section 2.2 of this report. The modelling is described in detail for each of the viaduct structures from Section 2.3 to Section 2.6 of this report. This includes details of the specific modelling methodologies, hydraulic constraints and any assumptions on each of the watercourse crossings.

Figure 1: Location plan



2.2 Culverts

2.2.1 This section describes the modelling for Ladbroke culvert (SWC-CFA16-004). The one dimensional ISIS hydraulic models built for the baseline and post scheme scenarios used the general methodologies for one dimensional modelling as discussed in Section 1.3 of this report. The impact of the scheme on peak flood levels is summarised in Table 2. The structure dimensions of width (W), height (H) and length (L) in metres is also provided in this table.

2.2.2 The methodology applied for the hydrological assessment is provided in the FEH proforma in Section 3 of this report.

Table 2: Modelled peak levels at culvert crossings

Watercourse identifier	Structure dimensions (WxHxL)	Flood event	Peak flood level		Change in flood level	Length of Impact Upstream Reach[7]
			Baseline	Scheme		
SWC-CFA16-004	3.6m x 2.1m x 35m	1 in 20 (5%)	99.423mAOD	99.323mAOD	-100mm	0m
		1 in 100 (1%) climate change	99.576mAOD	99.506mAOD	-70mm	
		1 in 1000 (0.1%)	99.667mAOD	99.705mAOD	38mm	

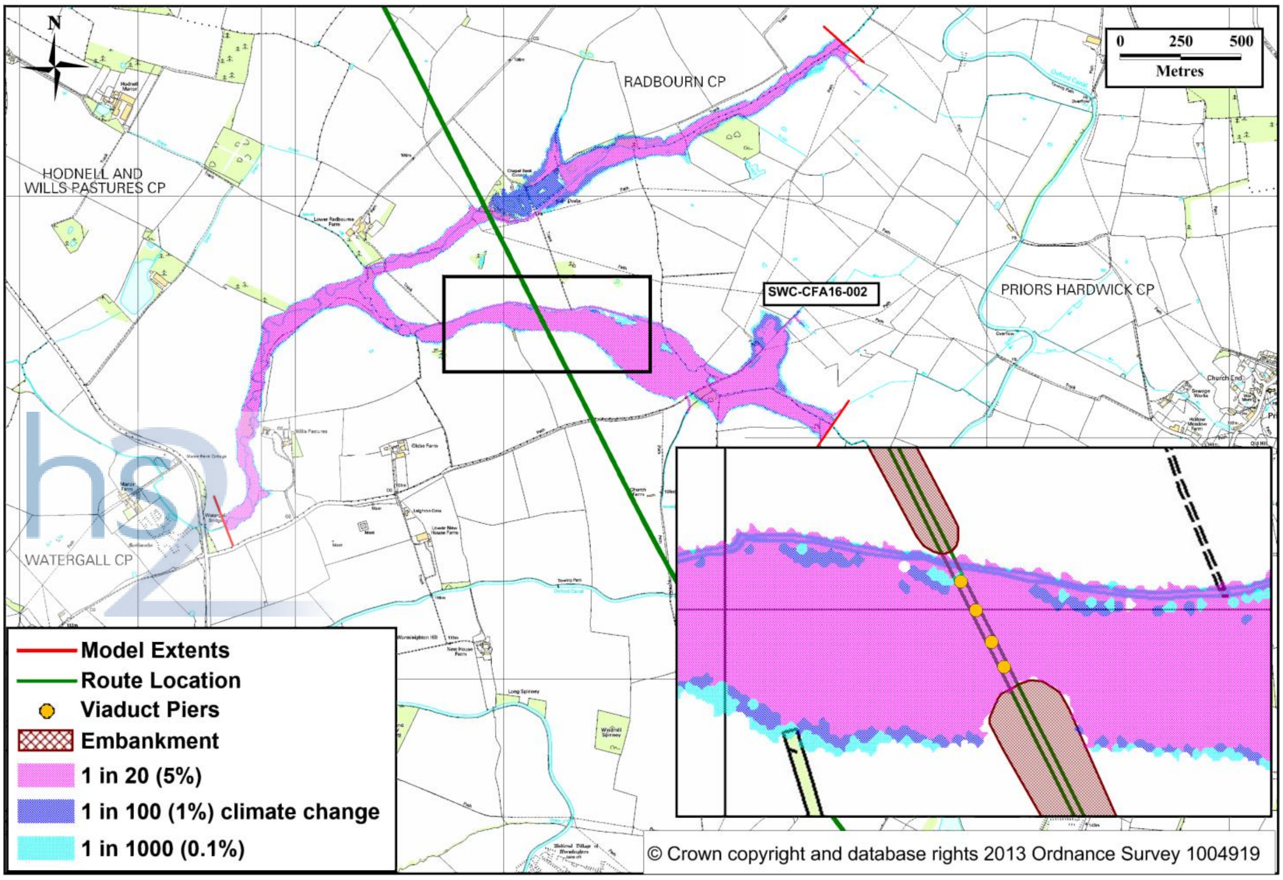
2.2.3 The model results show a localised decrease of peak levels of up to 70mm for the 1 in 100 (1%) annual probability with an allowance for climate change event at the structure with minimal changes elsewhere. Therefore, this culvert structure does not have any significant impact on flood risk.

2.3 Lower Radbourne south viaduct

2.3.1 The crossing will consist of an 89m-long viaduct at watercourse SWC-CFA16-002 (Volume 5: Map WR-05-041, F6). The watercourse flows from east of the crossing and continues west where it joins with watercourse SWC-CFA16-003 (Volume 5: Map WR-05-041, E6). The model extents and flood extents are provided in Figure 2.

[7] Length of reach upstream of the scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change event are greater than 10mm.

Figure 2: Crossing location plan and flood extents of Lower Radbourne south viaduct



Hydrology

2.3.2 There were no existing hydrological studies that had been carried out for this watercourse. The hydrological inflow was calculated using the ReFH method. The critical storm duration was calculated for the catchment at the location of the proposed crossing. Flows were then calculated based on these catchment descriptors as no suitable local donor station was identified. The details of the hydrological assessment are provided in the FEH proforma within Section 3 of this report. The flows at this crossing are summarised in Table 3.

Table 3: Hydrology results: model inflows for Lower Radbourne south viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA16-002	3	5.83m^3/s	10.05m^3/s	15.17m^3/s	Viaduct

Hydraulics

2.3.3 No existing hydraulic models were available for this watercourse. A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the Proposed Scheme, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.3.4 Watercourses within the modelled extent have been defined using the TUFLOW FC layer and the storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Bed levels and the width of watercourses have been estimated from the LiDAR DTM.

2.3.5 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.006. The gradient has been measured from the LiDAR along the channel bed at this location.

2.3.6 The Proposed Scheme model included the route embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.3.7 This desk based study has not identified any hydraulic constraints in the immediate vicinity of the crossing.

2.3.8 The baseline floodplain width at the crossing is 124m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak flood levels is shown in Figure 3. The modelled peak levels along with the Proposed Scheme impacts are summarised in Table 4.The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change are provided in Figure 4.

Figure 3: Cross section with flood levels for Lower Radbourne south viaduct

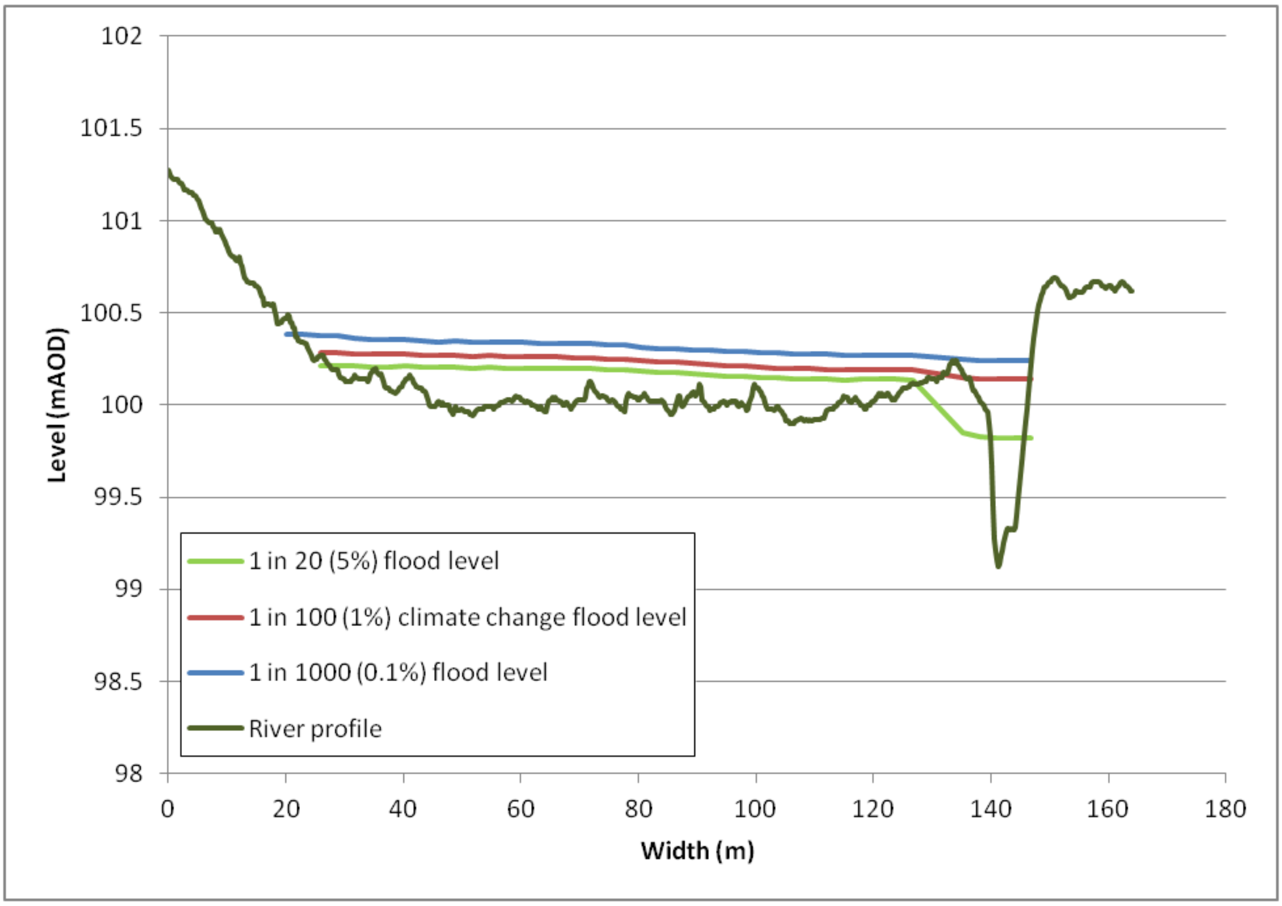
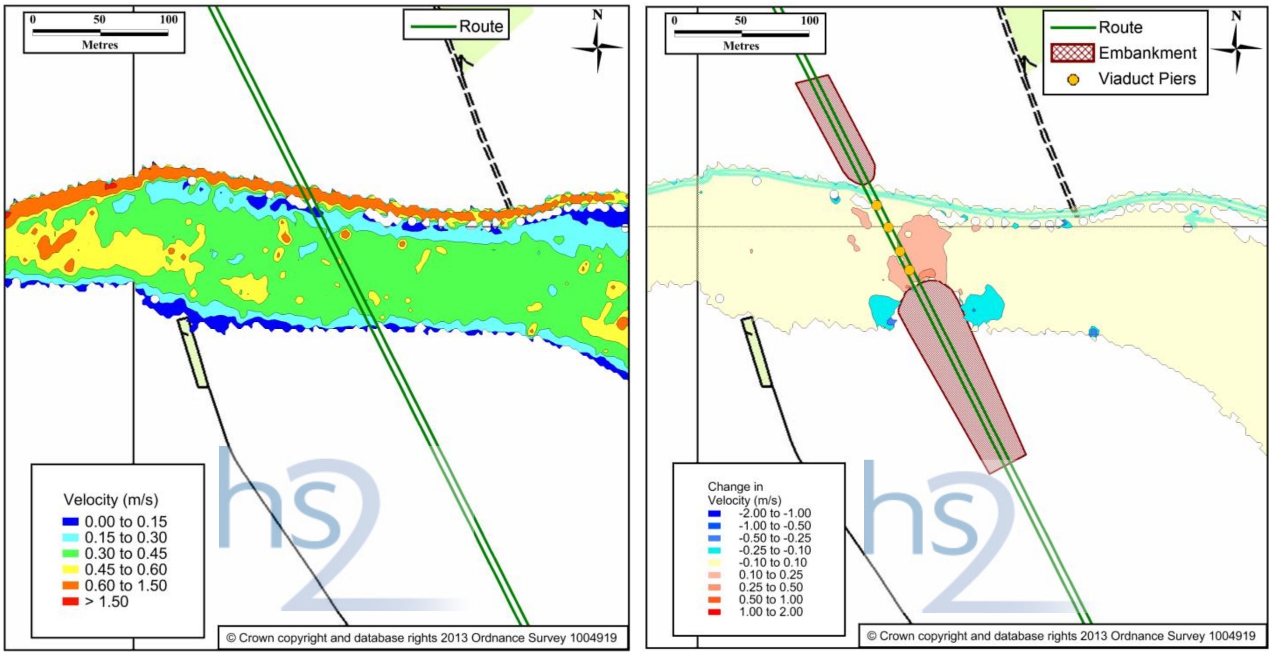


Table 4: Modelled peak levels for Lower Radbourne south viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	100.225mAOD	100.273mAOD	47mm
1 in 100 (1%) climate change	100.315mAOD	100.383mAOD	68mm
1 in 1000 (0.1%)	100.392mAOD	100.473mAOD	81mm

Figure 4: Baseline peak velocity contours and scheme impacts on velocities for 1 1n 100 (1%) climate change at Lower Radbourne south viaduct



Sensitivity assessment

2.3.9 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event in the baseline model. A 20% increase in flows caused up to 20mm increase in channel peak levels and 30mm increase in floodplain peak levels. A 20% decrease in flow caused up to 150mm decrease in channel peak levels and 30mm decrease in floodplain peak levels. Since the soffit level is sufficiently higher than the peak levels, any sensitivity allowance along with the impacts of the scheme would still provide the required clearance of 600mm.

2.3.10 There were noticeable changes in flood extents due to the variation of inflows. The 20% increase in flows caused increases in flood extent both upstream and downstream of the crossing. The increases in flood extent were greatest downstream of the crossing where increases of up to 5% were seen. Despite these increases no additional receptors have been affected as a result. Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

2.3.11 The proposed scheme showed increases of peak levels of up to 68mm for the 1 in 100 (1%) annual probability with an allowance for climate change event 20m upstream of the crossing. The length of reach with greater than 10mm increase was limited to

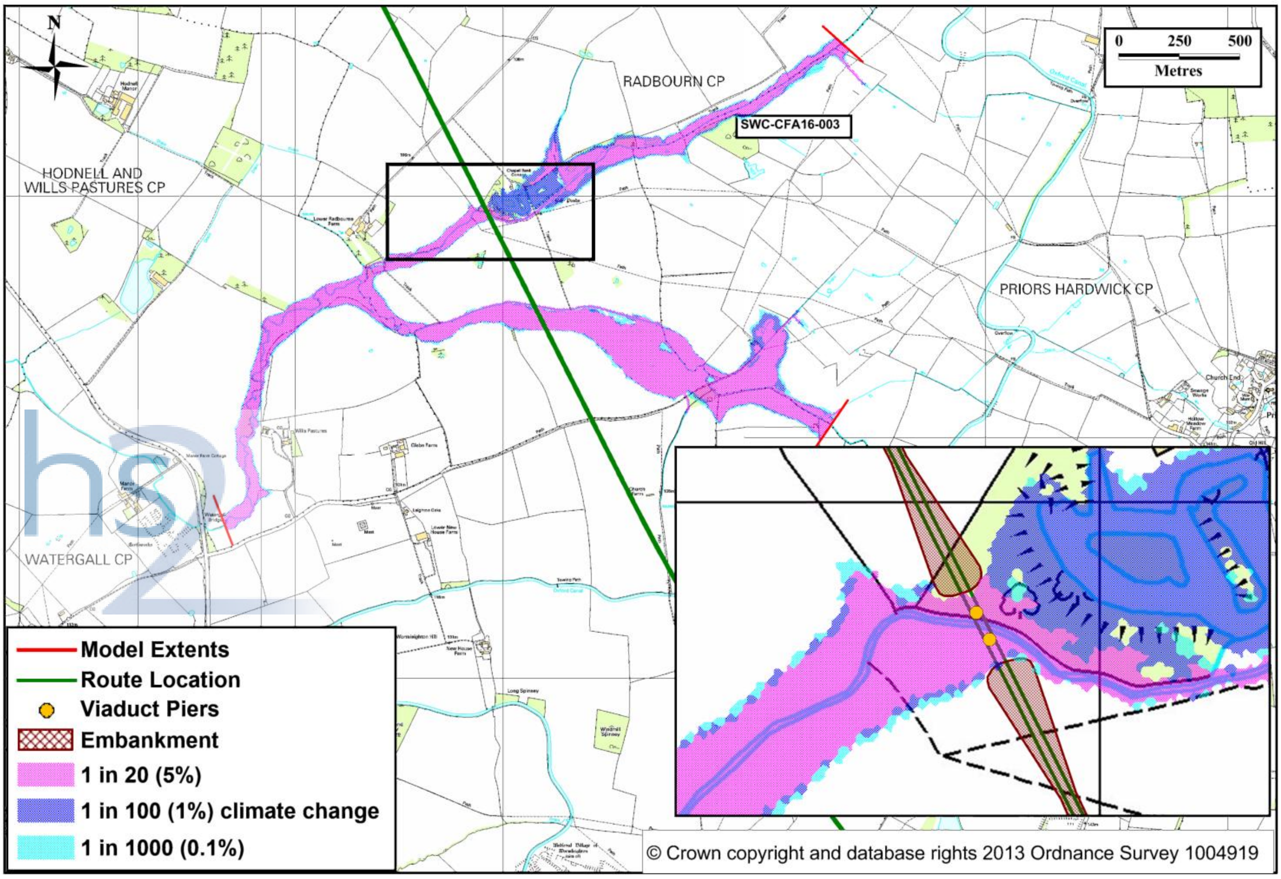
157m upstream of the crossing. A replacement flood storage area was identified which will provide like for like storage volume to mitigate the increase of flood risk.

2.3.12 There were localised increases of peak velocity of up to 0.34m/s at the crossing and with minimal changes elsewhere.

2.4 Lower Radbourne north viaduct

2.4.1 The crossing will consist of a 63m-long viaduct structure on watercourse SWC-CFA16-003 (Volume 5: Map WR-05-041, E6). The watercourse flows from north-east of the crossing and continues flowing south-west where is joins with watercourse SWC-CFA16-002 (Volume 5: Map WR-05-041, F6). The model extents and flood extents are shown in Figure 5.

Figure 5: Crossing location plan and flood extents for Lower Radbourne north viaduct



Hydrology

2.4.2 No existing hydrology was available for this watercourse. The hydrological inflow was calculated using the ReFH method. The catchment area was determined from the FEH CD-ROM. Catchment descriptors were extracted from the FEH CD-ROM and updated for urban expansion. The critical storm duration was calculated for the catchment at the location of the proposed crossing. Flows were then calculated based on these catchment descriptors as no suitable local donor station was identified. The details of the hydrological assessment are provided in the FEH proforma within Section 3 of this report. The flows at this crossing are summarised in Table 5.

Table 5: Hydrology results: model inflows for Lower Radbourne north viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA16-003	3	5.19m^3/s	8.92m^3/s	13.43m^3/s	Viaduct

Hydraulics

2.4.3 No existing hydraulic models were available for this watercourse. A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the Proposed Scheme, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.4.4 Watercourses within the modelled extent have been defined using the TUFLOW FC layer and the storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Approximate bed levels and watercourse widths have been taken from the LiDAR DTM.

2.4.5 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.006. The gradient has been measured from the LiDAR along the channel bed at this location.

2.4.6 The Proposed Scheme model included the route embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.4.7 The hydraulic constraints are several offline fish ponds which are located approximately 150m upstream of the proposed crossing. The storage capacity provided by these ponds during a flood event may impact on peak water levels at the crossing. The hydraulic model assumes that the ponds provide no additional storage during a flood event, hence resulting in a more conservative estimate of peak water level at the crossing.

2.4.8 The baseline floodplain width at the crossing is 65m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak flood levels is shown in Figure 6. The modelled peak levels along with the Proposed Scheme impacts are summarised in Table 6. The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change is provided in Figure 7.

Figure 6: Cross section with flood levels for Lower Radbourne north viaduct

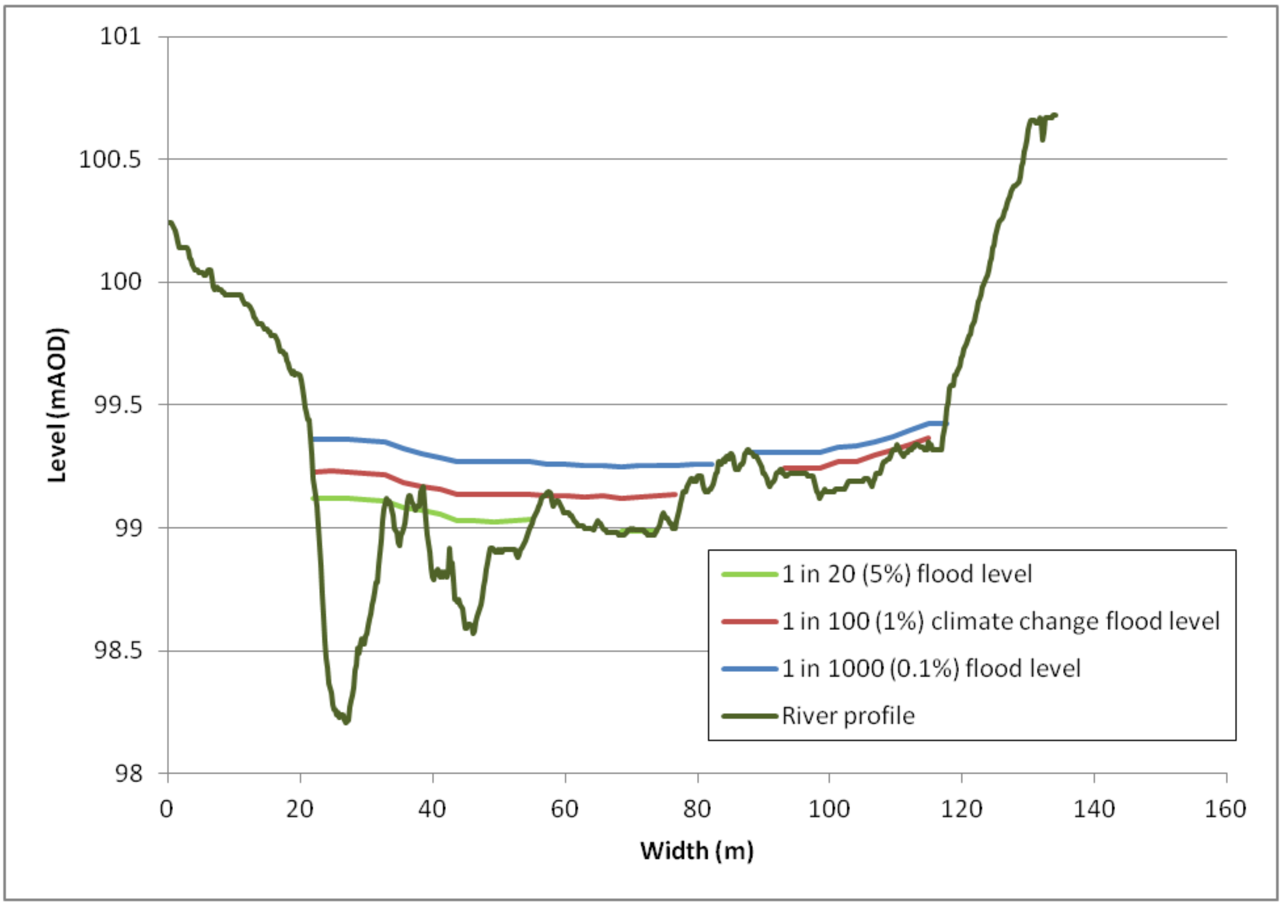
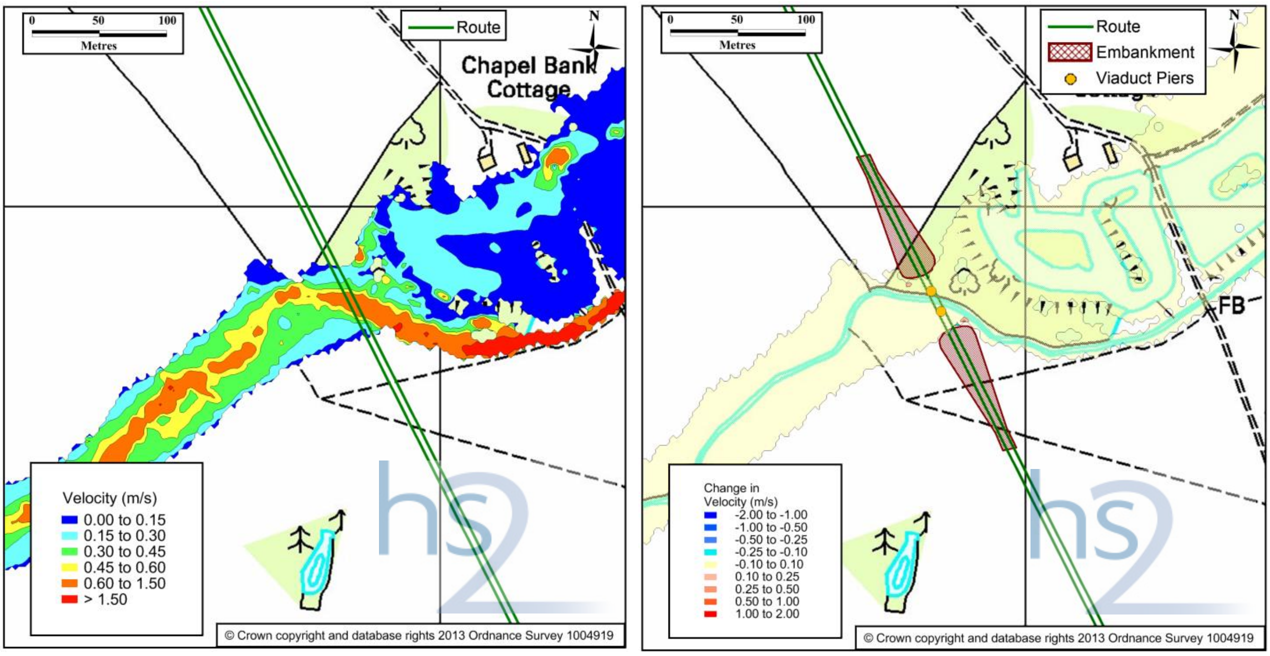


Table 6: Modelled peak levels for Lower Radbourne north viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	99.054mAOD	99.055mAOD	1mm
1 in 100 (1%) climate change	99.197mAOD	99.199mAOD	2mm
1 in 1000 (0.1%)	99.305mAOD	99.311mAOD	6mm

Figure 7: Baseline peak velocity contours and scheme impacts on velocities for the 1 in 100 (1%) climate change at Lower Radbourne north viaduct



Sensitivity assessment

2.4.9 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event on the baseline model. A 20% increase in flows caused up to 60mm increase in channel peak levels and 50mm increase in floodplain peak levels. A 20% decrease in flow caused up to 50mm decrease in both channel and floodplain peak levels. Since the soffit level is sufficiently higher than the peak levels, any sensitivity allowance along with the impacts of the scheme would still provide the required clearance of 600mm.

2.4.10 There were noticeable changes in flood extents due to the variation of inflows. The 20% increase in flows caused increases both upstream and downstream of the crossing. The increases in flood extent were greatest downstream of the crossing where increases of up to 5% were seen. Despite these increases no additional receptors have been affected as a result.

2.4.11 Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

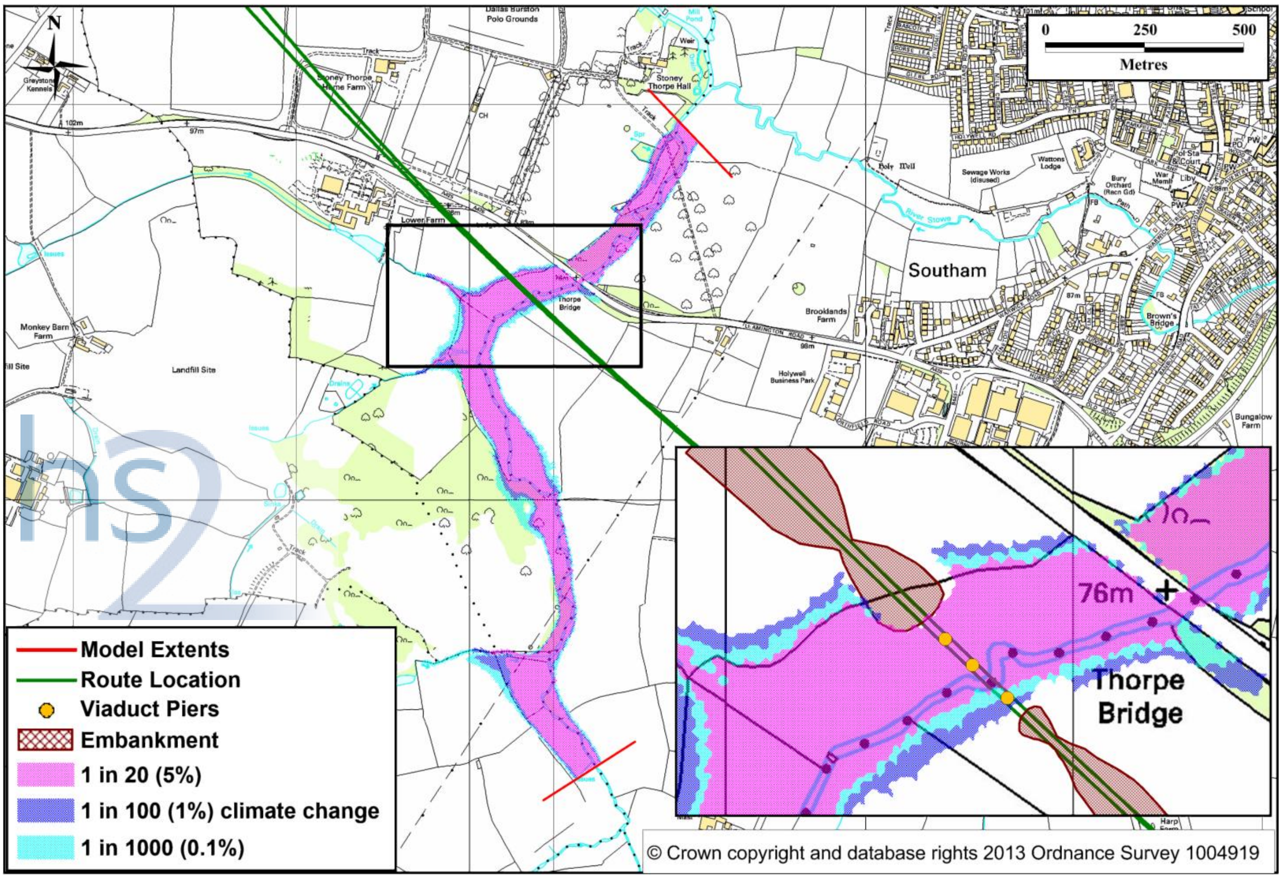
2.4.12 The proposed scheme showed minimal increases in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase of peak levels of greater than 10mm was limited to a 20m reach upstream of the crossing. There were minimal changes in velocities for this design event. Therefore, the proposed scheme will not have a significant impact on flood risk.

2.5 River Itchen viaduct

2.5.1 The crossing will consist of a viaduct structure of about 88m width on the River Itchen SWC-CFA16-005 (Volume 5: Map WR-05-043, E7). The watercourse flows from south-

west of the crossing continues north-east. The model extents and flood extents are shown in Figure 8.

Figure 8: Crossing location plan and flood extents for River Itchen viaduct



Hydrology

2.5.2 A hydrological inflow for the River Itchen was calculated as part of the River Leam Hazard Mapping Study[8]. Local data from the Southam gauge has been used to inform this inflow thus providing greater confidence in peak flow estimation. The FEH Statistical peak flows from the River Leam Hazard Mapping Study[8] are higher than the ReFH method peak flows calculated initially for this assessment. The ReFH hydrographs generated for this assessment were therefore fitted to the FEH Statistical peak flows from the River Leam Hazard Mapping Study and used within the hydraulic model. The FEH proforma detailing the FEH Statistical Method calculations is provided in the report for the hazard mapping study[8] and not reproduced here. Details of the ReFH method peak flows and hydrograph derivation are included in Section 3 of this report.

2.5.3 This calculated hydrograph has then been distributed across three sub-catchments and weighted based on sub-catchment area. The three sub-catchments are the main River Itchen at the River Itchen viaduct (SWC-CFA16-005), and two minor tributaries which are located upstream: Ladbroke culvert crossing (SWC-CFA16-004) and a minor tributary near the Southam culvert. This was carried out to ensure a realistic distribution of the inflows that were applied in the hydraulic model. The minor

[8] Environment Agency (2010), *River Leam Hazard Mapping*. Completed by JBA on behalf of the Environment Agency.

tributary near the Southam culvert will not be crossed by the route and hence was not modelled as a separate channel in the hydraulic model, but was included as an inflow at the confluence with the River Itchen. The Southam culvert (Volume 2: CFA16 Map Book, Map CT-06-084, B7 and B8) will be used only for conveying surface water flow. Details of the flow distribution between these three sub-catchments are provided in Table 7.

Table 7: Model inflows for River Itchen viaduct

Watercourse identifier where available[9]	Environment Agency Flood Zone	1 in 20 (5%) flow (m^3/s)	1 in 100 (1%) climate change flow (m^3/s)	1 in 1000 (0.1%) flow (m^3/s)	Modelled structure
SWC-CFA16-005	3	30.18m^3/s	61.78m^3/s	103.06m^3/s	Viaduct
Southam culvert		0.57m^3/s	1.17m^3/s	1.95m^3/s	-
SWC-CFA16-004		0.85m^3/s	1.73m^3/s	2.89m^3/s	Culvert

Hydraulics

2.5.4 No existing hydraulic model was available for the River Itchen; therefore a two dimensional TUFLOW hydraulic model has been constructed with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the Proposed Scheme, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.5.5 Watercourses within the modelled extent have been defined using the TUFLOW FC layer and the storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model, i.e. the conveyance of a 2m wide watercourse is able to be represented using a 5m model cell resolution. Bed levels and the width of watercourses have been estimated from the LiDAR DTM.

2.5.6 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed gradient of 0.002. The gradient has been measured from the LiDAR along the channel bed at this location.

2.5.7 The Proposed Scheme model included the HS2 route embankment, assuming the soffit of the viaduct is sufficiently high so as to not impact on the results. The embankment was represented as Z-shape polygon layers. Piers were not included in this model.

2.5.8 There are two key hydraulic constraints for this model. First, Thorpe Bridge (A425) which is located approximately 100m downstream of the proposed crossing. Due to the close proximity of the two structures, the constriction at Thorpe Bridge is likely to impact on water levels at the crossing. Thorpe Bridge has been represented in the current model in the same manner in which the watercourse has been represented,

[9] There was no watercourse identifier for Southam culvert (Volume 2: CFA16 Map Book, Map CT-06-084, B7 and B8).

and assumes the width of the structure is the same as the watercourse. The structure is currently modelled with no soffit or deck level.

2.5.9 Secondly, the LiDAR DTM shows that the A425 is an embankment and retains any out of bank flood waters behind it. Crest levels of the road embankment have been extracted from the LiDAR DTM and added in the model. The current model results show that the road is not overtopped for all flood events up to and including the 1 in 1000 (0.1%) annual probability event.

2.5.10 The baseline floodplain width at the crossing is 114m for a 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section with peak flood levels is shown in Figure 9. The modelled peak levels along with the Proposed Scheme impacts are summarised in Table 8. The baseline peak velocities and scheme impacts for the 1 in 100 (1%) annual probability with an allowance for climate change are provided in Figure 10.

Figure 9: Cross section with flood levels for River Itchen viaduct

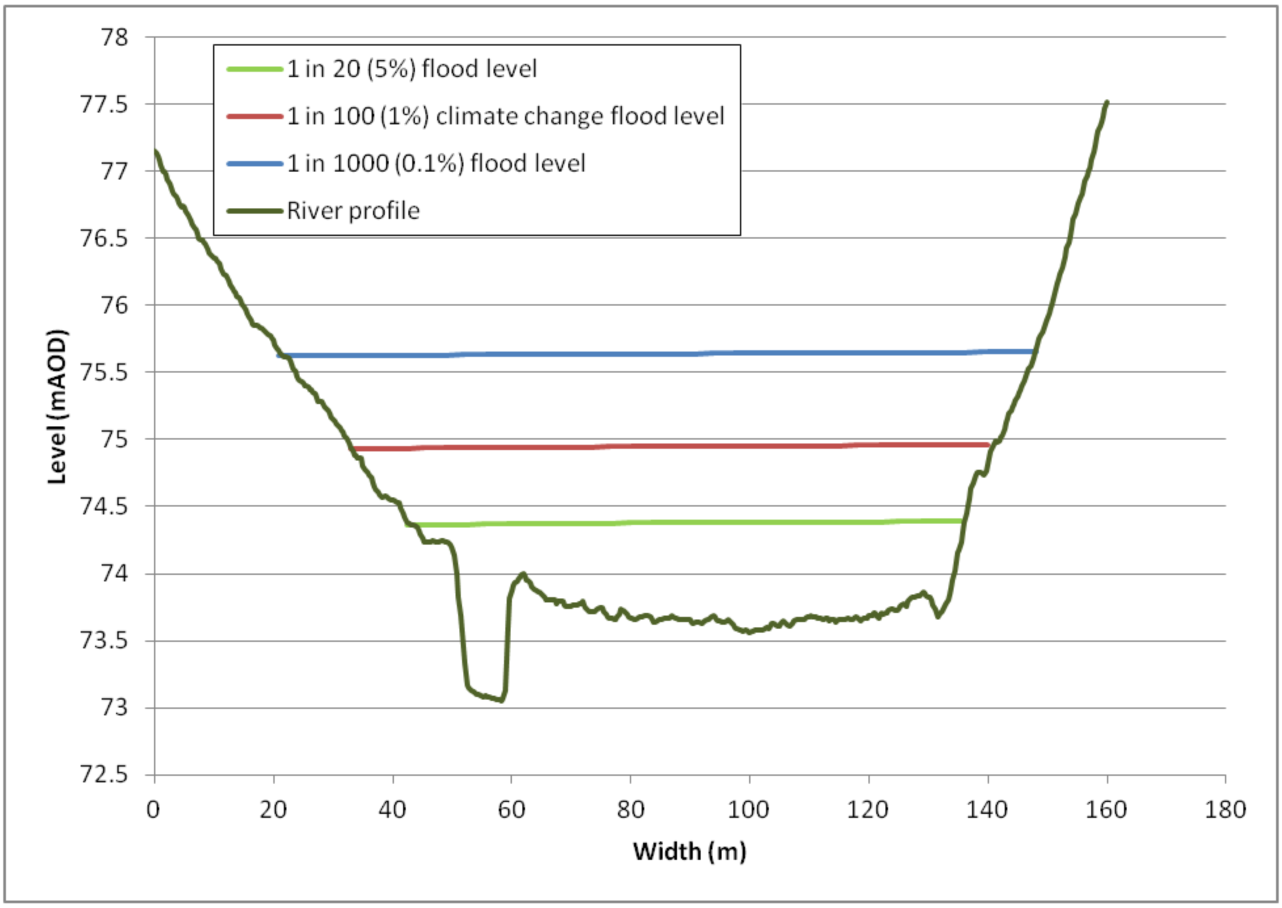
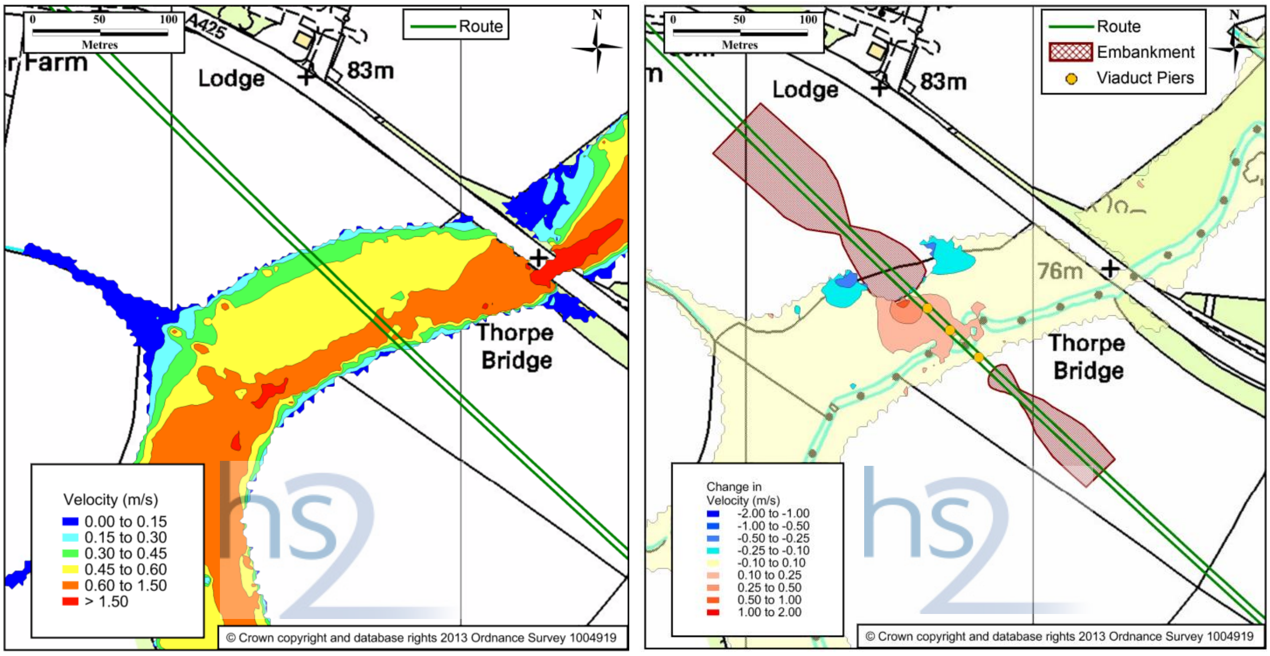


Table 8: Modelled peak levels for River Itchen viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	74.379mAOD	74.408mAOD	29mm
1 in 100(1%) climate change	74.947mAOD	74.967mAOD	20mm
1 in 1000 (0.1%)	75.639mAOD	75.651mAOD	12mm

Figure 10: Baseline peak velocity contours and scheme impacts on velocities for 1 in 100 (1%) climate change event at River Itchen viaduct



Sensitivity assessment

2.5.11 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event on the baseline model. A 20% increase in flows caused up to 420mm increase in both channel and floodplain peak levels. Since the soffit level is sufficiently higher than the peak levels, any sensitivity allowance along with the impacts of the scheme would still provide the required clearance of 600mm. A 20% decrease in flow caused up to 220mm decrease in both channel and floodplain peak levels.

2.5.12 There were noticeable changes in flood extents due to the variation of inflows, with the 20% increase in flows resulting in overall increases in flood extent of 12%. Despite these increases in peak levels and flooded extent no additional receptors apart from agricultural land have been affected as a result.

2.5.13 Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

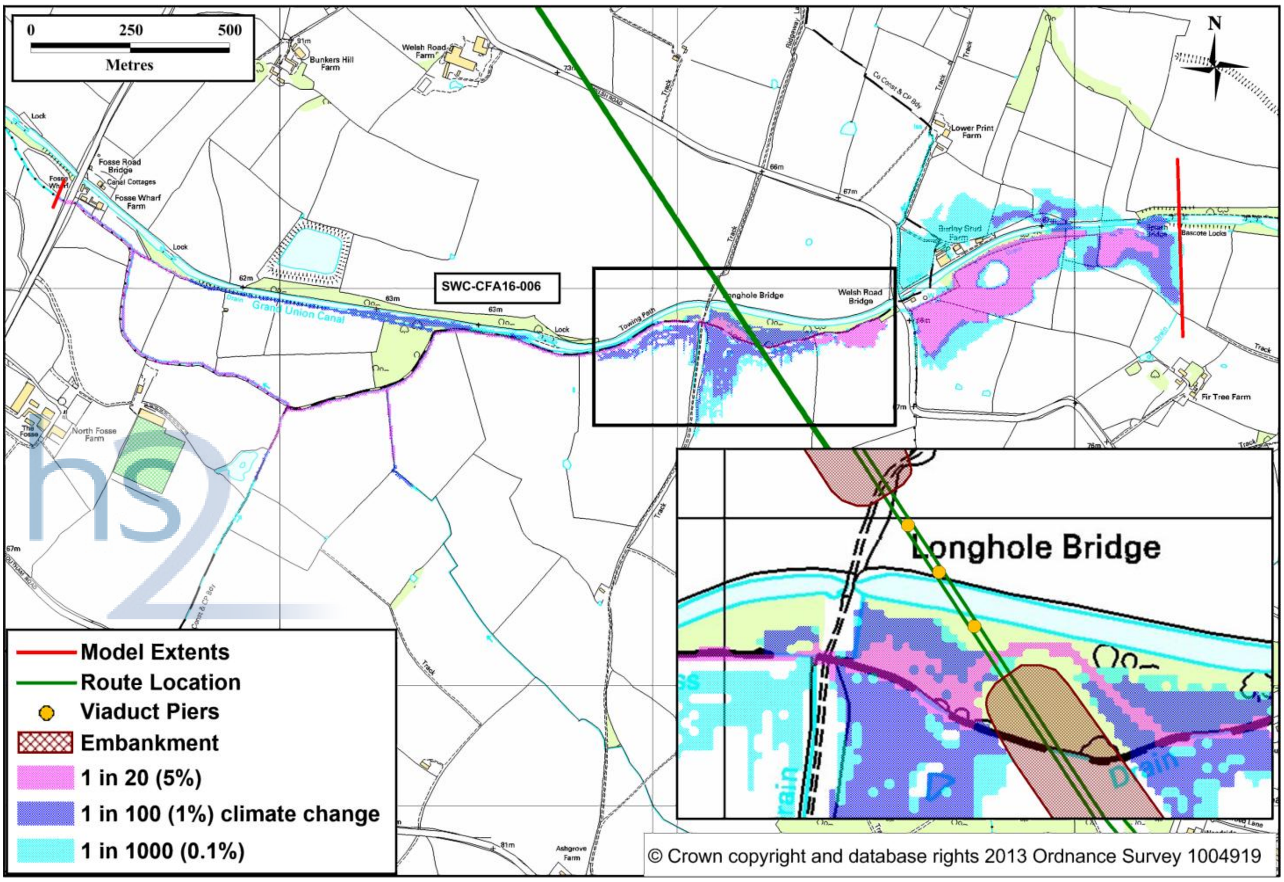
2.5.14 The proposed scheme showed up to a 20mm increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase in peak level of greater than 10mm was limited to a 480m reach upstream of the crossing, along which there were no other receptors other than agricultural land. There were localised increases in velocities of up to 0.5m/s at the crossing and with minimal changes elsewhere.

2.5.15 A replacement flood storage area was identified which will provide a like for like storage volume to mitigate the increase of flood risk.

2.6 Longhole viaduct

2.6.1 This crossing consists of a 135m-long viaduct structure which will cross the ordinary watercourse SWC-CFA16-006 (Volume 5: Map WR-05-044a, E6) as shown in Figure 11. The watercourse flows from east of the crossing and continues west within the model extents shown in Figure 11.

Figure 11: Crossing location plan and flood extents for Longhole viaduct



Hydrology

2.6.2 No existing hydrology was available for this watercourse. The hydrological inflow was calculated using the ReFH method for the drain to the south of the canal. The catchment area was determined from the FEH CD-ROM. Catchment descriptors were extracted from the FEH CD-ROM and updated for urban expansion. The critical storm duration was calculated at the location of the proposed crossing. Flows were then calculated based on these catchment descriptors as no suitable local donor station was identified. A hydrological inflow has not been calculated, nor applied, along the Grand Union Canal. Details of the hydrological assessment are provided in Section 3 of this report. The flows at the crossing are provided in Table 9.

Table 9: Hydrology results: model inflows for Longhole viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA16-006	3	4.70m^3/s	6.92m^3/s	Viaduct

Hydraulics

2.6.3 No existing hydraulic models were available for this watercourse. A TUFLOW model has been constructed and built with a 5m cell resolution. The topography of the model is based upon 5m resolution LiDAR data. Around the location of the route, more detailed 0.2m resolution LiDAR data has been utilised. A Manning's n value of 0.05 has been used to define the floodplain and a value of 0.03 has been used to define the watercourse. These values have been selected based on a desk-based study.

2.6.4 Watercourses within the modelled extent have been defined using the TUFLOW flow constriction and storage reduction factor functions. These allow for the capacity of the channel to be reduced and not limited to the cell resolution of the model. Approximate bed levels and watercourse widths have been taken from the LiDAR DTM.

2.6.5 The elevation taken from the LiDAR DTM has been used to represent the water level of the Grand Union Canal. Upstream of Welsh Road, the Canal is shown to be at the same elevation as the road, whereas downstream there is a drop in elevation of approximately 1m.

2.6.6 An HQ boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed floodplain gradient of 0.003. The gradient has been measured from the LiDAR along the channel bed at this location.

2.6.7 The Proposed Scheme model includes the diverted watercourse and the Proposed Scheme embankment. The viaduct soffit has been assumed sufficiently high as to not impact on the results. Piers were not included in this model.

2.6.8 There are two key hydraulic constraints to this model. First, Welsh Road Bridge is located approximately 400m upstream of the crossing. The road is raised as it passes over the Grand Union Canal and the drain, and acts as an embankment, retaining out of bank floodwaters behind it. The crest level of the road has been extracted from the LiDAR DTM and added in the model. Aerial photography shows that the Grand Union Canal is controlled by a lock at this location, with differing water levels upstream and downstream of the structure. The differing elevations have been represented in the model; however the lock is not specifically represented. The drain is culverted beneath the road embankment and has been modelled in 1D with the width of the structure equal to the width of the watercourse. The soffit level was estimated by calculating the depth between the crest of the road embankment and the bed level of the drain, minus the clearance required above the flood levels.

2.6.9 Secondly, Longhole Bridge is located approximately 50m downstream of the crossing. The track is raised as it passes over both the Grand Union Canal and the drain. The crest level of the road has been extracted from the LiDAR DTM and enforced in the model. The details of the hydraulic structures on the Grand Union Canal and drain are unknown and have been crudely represented by carving the watercourse through the embankment, such that the structures have no soffit or deck level. The model results currently show some retention of floodwaters behind this embankment.

2.6.10 The baseline floodplain width at the crossing is 138m for the 1 in 100 (1%) annual probability with an allowance for climate change event. The cross section of the

watercourse with baseline flood levels upstream of the crossing is shown in Figure 12. The impact of the Proposed Scheme on modelled peak levels is summarised in Table 10. The baseline and Proposed Scheme peak velocity contours are shown in Figure 13.

Figure 12: Cross section and flood levels for Longhole viaduct

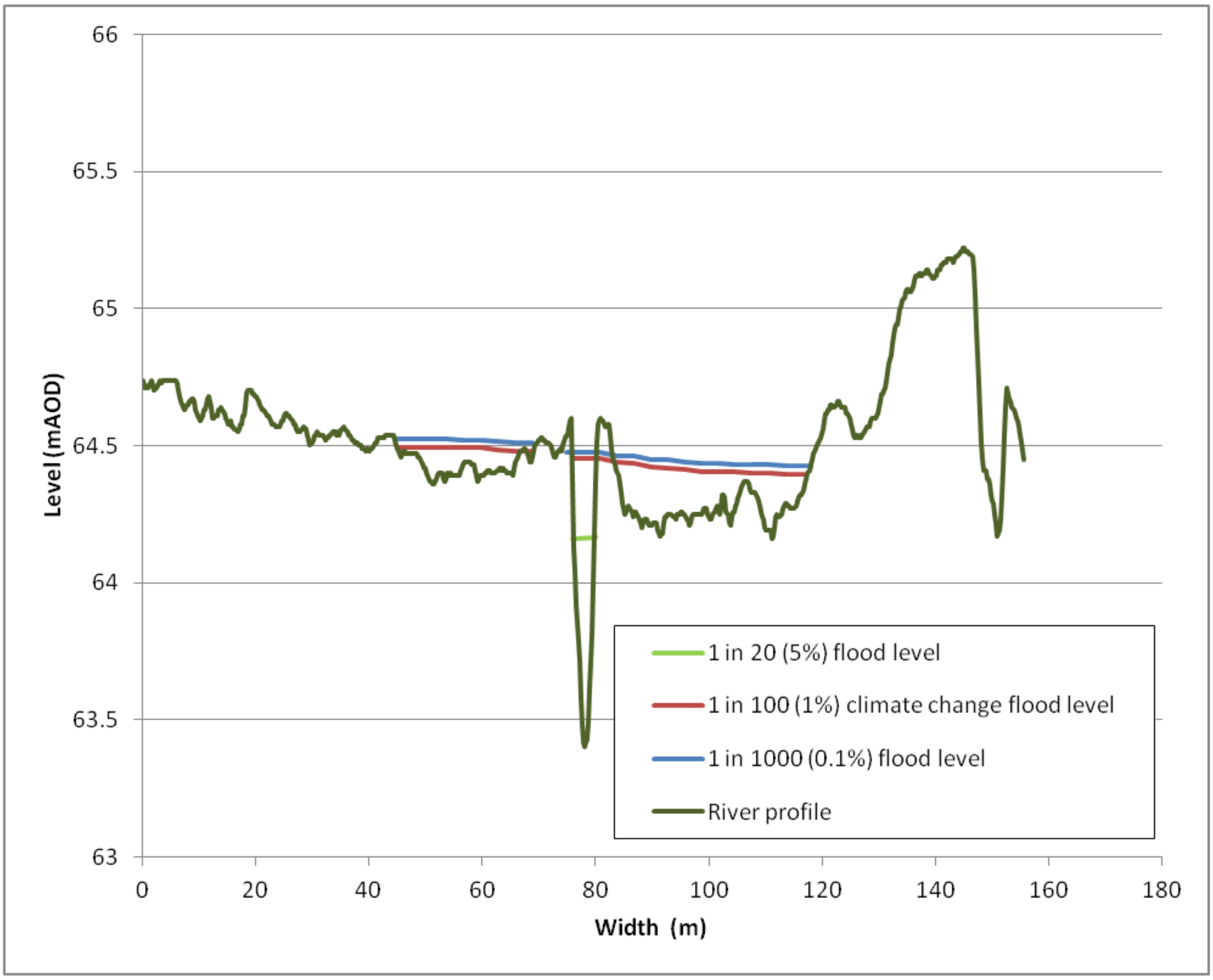
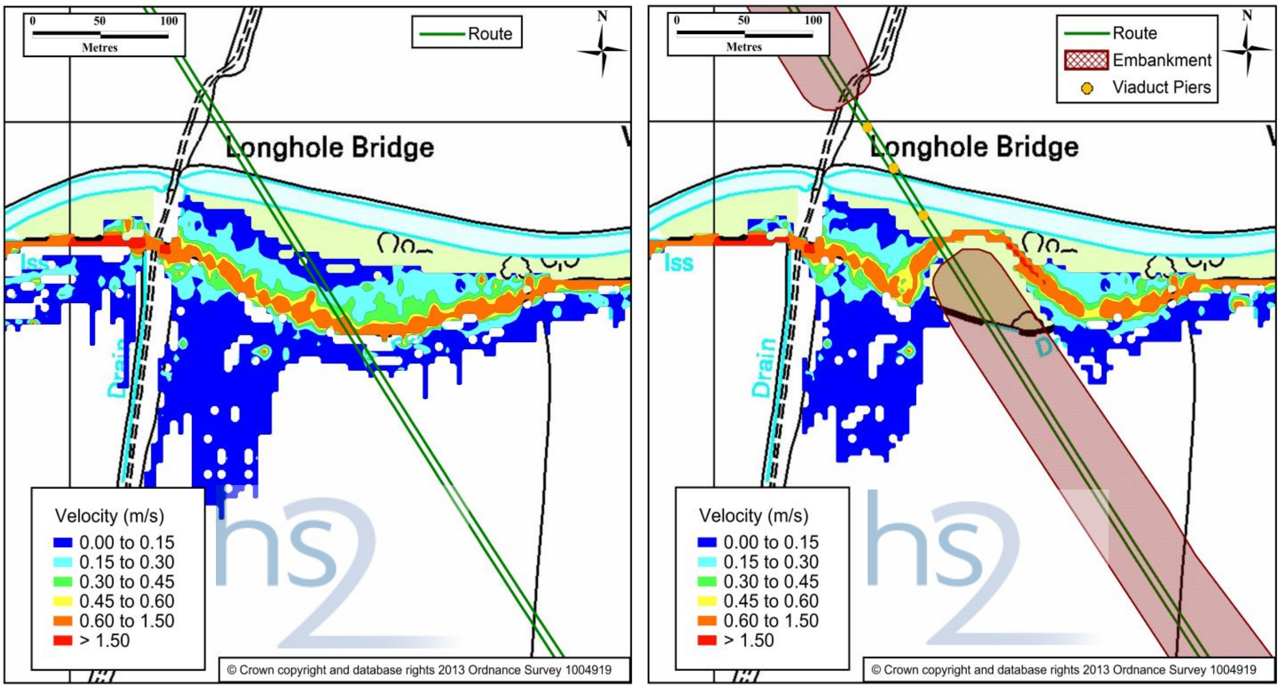


Table 10: Modelled peak levels for Longhole viaduct

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 20 (5%)	64.163mAOD	64.163mAOD	0mm
1 in 100 (1%) climate change	64.437mAOD	64.476mAOD	39mm
1 in 1000 (0.1%)	64.470mAOD	64.604mAOD	134mm

Figure 13: Baseline and Proposed Scheme peak velocity contours for 1 in 100 (1%) climate change event at Longhole viaduct



Sensitivity

2.6.11 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event in the baseline model. A 20% increase in flows caused up to 10mm increase in channel peak levels and no change in floodplain peak levels. A 20% decrease in flow caused up to 30mm decrease in channel peak levels and 10mm decrease in floodplain peak levels.

2.6.12 The increase in flows resulted in increases in flood extent of 47% to the west of Welsh Road Bridge which will affect some additional receptors such as buildings. However, the Proposed Scheme has been shown to have impacts within 72m upstream of the crossing which is east of Welsh Road Bridge. Since, the change in flood extent is outside the zone of impact; the Proposed Scheme will not affect the flood risk at this particular location.

Conclusions

2.6.13 The proposed scheme showed up to a 39mm rise in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. The increase of peak levels of greater than 10mm was limited to a 90m reach upstream of the crossing, along which there were no other receptors other than agricultural land.

2.6.14 A replacement flood storage area was identified which will provide a like for like storage volume to mitigate the increase in flood risk.

2.6.15 There are localised increases in velocity near the crossing of up to 0.45m/s.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH Proforma for the hydrological calculations for the watercourses for which there was no existing hydrology available.

3.1.2 The FEH Proforma is based on the Environment Agency supporting document to the flood estimation guidelines.

3.1.3 The watercourse crossings in this study area covered in the FEH Proforma are the Lower Radbourne South viaduct (SWC-CFA16-002), Lower Radbourne North viaduct (SWC-CFA16-003) and Longhole viaduct (SWC-CFA16-006).

3.1.4 For the River Itchen viaduct (SWC-CFA16-005) and the Ladbroke culvert (SWC-CFA16-004), the hydrology for the River Itchen and its tributary using the FEH Statistical method has been taken from the River Leam Hazard Mapping Study[8]. The FEH proforma for the hydrological assessment using the FEH Statistical method is provided as part of this Hazard Mapping Study, and hence not reproduced here. However, as mentioned in Section 2.5.2 of this report, ReFH method peak flows were calculated initially for this assessment to compare to the FEH Statistical method flows, derived both in this previous study and re-assessed as part of this current study. Following comparison, the hydrological inflows selected utilised the ReFH hydrographs fitted to the peak flow estimates from the River Leam Hazard Mapping Study FEH Statistical method. Therefore, the details of the ReFH method for peak flow and hydrograph derivation is provided in this section.

3.2 Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx. no. of flood estimates required Peak flows or hydrographs? Range of return periods and locations Approx. time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk. As part of the Proposed Scheme, structures may need to be incorporated into the design where a number of watercourses pass beneath the route. The capacity of these structures needs to be determined to ensure there is no increase to flood risk. It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines a lower flow, and hence smaller structures would have sufficient capacity, this is acceptable. Flows are required at all watercourse crossings within the study area. Catchments within this study area include the River Itchen. This assessment outlines the derivation of flows and hydrographs at four locations for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The four crossings have separate catchments which range in size from $3.73km^2$ to $77.95km^2$ and are largely rural.

Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.1.2, December 2011.

Gauging stations (flow or level)

3.2.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.2.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Water-course	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level ...)	Start and end of flow record
N/A							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
N/A						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating – e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	No				

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from Environment Agency	Date obtained	Details
Other data or information (e.g. groundwater, tides)	No				

Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes. The bullet points below summarise the general approach to flow estimation for these four catchments of which three are classed as minor watercourses and one as a main river/larger watercourse. The major watercourse crossing is the River Itchen viaduct (SWC-CFA16-005). For minor watercourses the following approach has been followed: - define catchment area either on the FEH CD-ROM or using the DTM if catchment area is <0.5km^2; - check catchment descriptors and adjust where necessary; - calculate critical duration for the catchment of each crossing using the equation, D (hrs) = Tp*(1+SAAR/1000); and - calculate flows using the ReFH method from catchment descriptors. Main rivers and larger watercourses: - extract catchment descriptors from the FEH CD-ROM and check; - search for a local donor station (using the FEH CD-ROM and in pooling group); - derive flow estimates using both ReFH and FEH Statistical methods; - calculate critical duration for the catchment of each crossing using the equation, D (hrs) = Tp*(1+SAAR/1000); - review existing hydrology studies for the catchments of major crossings where available; and - compare flow estimates and make recommendations for flows to be used in modelling. For the River Itchen viaduct (SWC-CFA16-005) FEH Statistical flows have already been derived in the River Leam Hazard Mapping Study for a location just downstream of this crossing. However as part of a review of the suitability of the flows derived for this previous study, the FEH Statistical method has been repeated for this catchment as a comparison. Due to the hydrological setting, the peak flows derived for this location will then be distributed across three sub-catchments and weighted based on sub-catchment area. The three sub-catchments are the main River Itchen at the River Itchen viaduct (SWC-CFA16-005), and two minor tributaries which are located upstream: Ladbroke culvert crossing (SWC-CFA16-004) and a minor tributary near the Southam culvert. This will be carried out to ensure a realistic distribution of the inflows is applied in the hydraulic model. This therefore results in the derivation of peak flows and hydrographs for six catchments, five of which are minor watercourses, where for two of these flows will be derived based on area-scaling only.

Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	The main sites of interest are at the crossing locations and hence are the points at which flows have been derived. Each point at which flows have been derived has been named in accordance with the associated watercourse identifier at the crossings. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge.
Any unusual catchment features to take into account? **e.g. highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	All the catchments are within a suitable range of urbanisation for the ReFH method. All catchments have a FARL >0.9. No catchments are classed as highly permeable.
Initial choice of method(s) and reasons **Will the catchment be split into sub-catchments? If so, how?**	For the purposes of this assessment, crossings of these minor watercourses used the ReFH method based on catchment descriptors.
Software to be used (with version numbers)	FEH CD-ROM v3.0[10] WINFAP-FEH v3.0[11] ReFH calculations – ReFH spreadsheet / ISIS

Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	Catchment area on FEH CD-ROM	Revised catchment area if altered
SWC-CFA16-006	Ordinary watercourse (tributary of the River Leam)	Route crossing at structure shown in the site code column.	438,200	263,850	3.73km^2	Not altered

[10] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[11] *WINFAP-FEH v3* © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

Site code	Watercourse	Site	Easting	Northing	Catchment area on FEH CD-ROM	Revised catchment area if altered
SWC-CFA16-005	Non-main river (River Itchen)	Route crossing at structure shown in the site code column	440150	261500	77.95km²	Not altered
Southam culvert	Non-main river	Route crossing at structure shown in the site code column. This crossing does not have a watercourse identifier.	441300	260500	1.41km²	Not altered
SWC-CFA16-004	Ordinary watercourse (tributary of the River Itchen)	Route crossing at structure shown in the site code column	443050	258550	2.09km²	Not altered
SWC-CFA16-003	Ordinary watercourse (tributary of the River Itchen)	Route crossing at structure shown in the site code column.	443,850	256,900	7.55km²	Not altered
SWC-CFA16-002	Ordinary watercourse (tributary of the River Itchen)	Route crossing at structure shown in the site code column.	444,100	256,550	8.63km² (adjusted where the FEH CD-ROM boundary included the canal)	7.76
Reasons for choosing above locations		Locations where the Proposed Scheme will cross the respective watercourses with the addition of the Southam culvert as explained in the 'Initial choice of approach' section. The Southam culvert crossing was used as a location for deriving the catchment area for the watercourse near this location. The watercourse near Southam culvert and SWC-CFA16-004 are provided here to detail their catchment areas which will be used later to distribute flows from River Itchen which will be derived for the major watercourse: SWC-CFA16-005.				

Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
SWC-CFA16-006	1.000	0.30	0.336	1.50	33.7	633	47.22	0.0054	0.0021
SWC-CFA16-005	0.989	0.30	0.247	10.99	31.70	641	51.46	0.010	0.011
SWC-CFA16-003	0.982	0.30	0.225	3.11	24.5	651	52.66	0.0000	0.0046
SWC-CFA16-002	0.989	0.30	0.237	3.07	41.5	653	52.81	0.0121	0.0073

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The boundary of each catchment has been checked against contours from OS 50K mapping and DTM where available. Adjustment to the catchment boundaries and area was made where necessary. The boundary of catchments not represented on the FEH CD-ROM was determined using the DTM. Changes to the catchment boundary and resulting area are provided in the earlier section of 'Summary of subject sites'.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	Broad scale checks of catchment descriptors have been carried out. The catchment descriptors for catchments not represented on the FEH CD-ROM were extracted for downstream or adjacent catchments. The catchment area was adjusted and the DPLBAR was recalculated based on the new catchment area (FEH CD-ROM catchment area^0.548). For all catchments, where the catchment area has changed the new catchment area has been used to calculate the DPLBAR (FEH CD-ROM catchment area^0.548). The average slope has been calculated using the Weighted Height-Distance Method. Other catchment descriptors were sensibility checked for suitability. The underlying geology and soils have been reviewed on a broad scale for the larger area of interest and the catchment values for BFIHOST and SPRHOST values appear reasonable: no changes were considered necessary at this stage.
Source of URBEXT	URBEXT1990 (ReFH method)
Method for updating of URBEXT	CPRE formula from FEH Volume 4 on URBEXT1990 / CPRE formula from 2006 CEH report on URBEXT2000.

Statistical method

3.2.3 Peak flows from the FEH Statistical method have been calculated at the River Itchen viaduct crossing (SWC-CFA16-005). These flow estimates were used for comparison with flow estimates derived from the ReFH method and also the FEH Statistical method derived for use in the River Leam Hazard Mapping Study[8].

Search for donor sites for QMED (if applicable)

Comment on potential donor sites **Mention:** **Number of potential donor sites available** **Distances from subject site** **Similarity in terms of catchment area, BFIHOST, FARL and other catchment descriptors** **Quality of flood peak data** **Include a map if necessary. Note that donor catchments should usually be rural.**	Potential donor sites were sought for the catchments of the major crossings using the FEH CD-ROM, HiFlows-UK database and from within the pooling groups. Stations within a reasonable distance of the catchments of the crossings were either significantly larger, heavily urbanised or had very different catchment descriptors and were considered unsuitable donor stations. The asg factor applied to more distant potential donor stations negated the adjustment of QMED.

Donor sites chosen and QMED adjustment factors

National River Flow Archive no.	Reasons for choosing or rejecting	Method (annual maxima or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
No suitable donor stations have been identified. QMED has been calculated from catchment descriptors. Please refer to comments in the section 'Search for donor sites for QMED (if applicable)'.						

Which version of the urban adjustment was used for QMED at donor sites, and why? **Note: The guidelines recommend great caution in urban adjustment of QMED on catchments that are also highly permeable (BFIHOST>0.8).**	

Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED	Data transfer	Final estimate of QMED
SWC-CFA16-005	CD (QMED rural)	14.519m^3/s	N/A	14.519m^3/s

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	N/A – Estimates for different catchments
Which version of the urban adjustment was used for QMED, and why?	Bayliss (2007) – appropriate method at the time of the assessment.

Derivation of pooling groups

3.2.4 The composition of the pooling groups is given in Section 3.3 of this report. Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
River Itchen @ Cr25	SWC-CFA16-005	No	Refer to Section 3.3 of this report	N/A

Notes

Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.

Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 1 in 100 (1%)
SWC-CFA16-005	P	River Itchen @ Cr25	Generalised logistic	N/A	Location 1 Scale 0.27 Shape – 0.1 Bound – 1.87	2.58

Notes

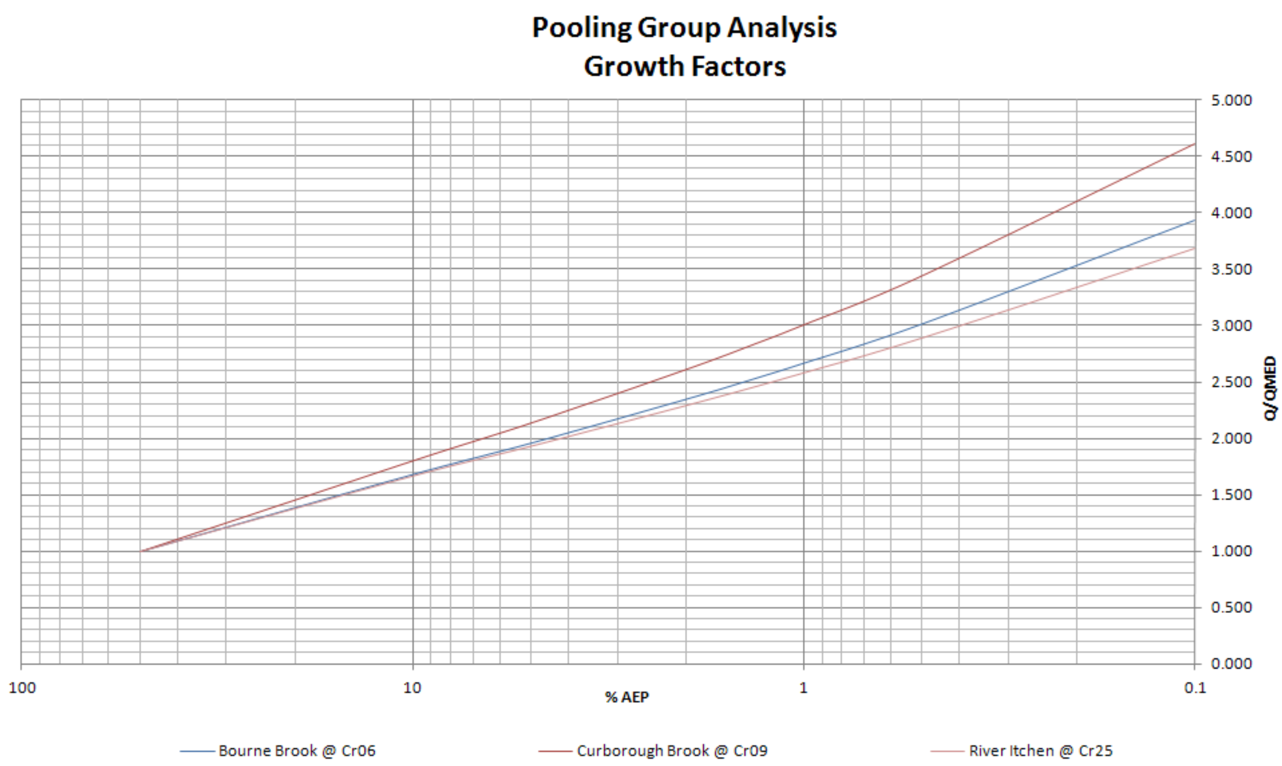
Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments to growth curves should use the version 3 option in WINFAP-FEH: Kjeldsen (2010).

Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following flood events							
	1 in 2 (50%)	1 in 10 (10%)	1 in 20 (5%)	1 in 50 (2%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 200 (0.5%)	1 in 1000 (0.1%)
SWC-CFA16-005	14.52	24.23	28.04	33.26	35.69	37.46	41.90	53.40



Please note that although the growth factors of the pooling groups of Bourne Brook@Cr06 and Curborough Brook@Cr09 are shown here they have not been used in any hydrological assessment for CFA16. They will be used in the hydrological estimates in the modelling report for CFA22 (WR-004-015).

Revitalised flood hydrograph (ReFH) method

Parameters for ReFH model

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	Cmax (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
SWC-CFA16-006	CD	2.71	282.66	30.98	0.75
SWC-CFA16-005	CD	8.97	211.01	40.17	0.54
SWC-CFA16-003	CD	4.67	193.12	30.39	0.49
SWC-CFA16-002	CD	3.85	202.89	29.96	0.51
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		Potential donor sites were sought for the catchments of major crossings using the FEH CD-ROM, HiFlows-UK database and from within the pooling groups. In general stations local to the catchments were either significantly larger, heavily urbanised or had very different catchment descriptors and were unsuitable donor stations.			

Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
SWC-CFA16-006	Rural	Winter	4.4	ReFH Design Standard
SWC-CFA16-005	Rural	Winter	14.7	ReFH Design Standard
SWC-CFA16-003	Rural	Winter	7.7	ReFH Design Standard
SWC-CFA16-002	Rural	Winter	6.4	ReFH Design Standard
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			Storm durations have not been optimised within the hydraulic model. It is unlikely that the storm durations will be altered as part of the next stage of hydraulic modelling.	

Flood estimates from the ReFH method

Site Code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
SWC-CFA16-006	2.76	3.92	4.70	6.92
SWC-CFA16-005	32.48	45.05	54.06	77.48
SWC-CFA16-003	5.19	7.43	8.92	13.43
SWC-CFA16-002	5.83	8.37	10.05	15.17

Discussion and summary of results

Comparison of results from different methods

3.2.5 This table compares peak flows from various methods with those from the FEH Statistical method for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

3.2.6 For SWC-CFA16-005, the River Leam Hazard Mapping Study[8] was used to provide flow estimates from previous studies.

Site code	Peak Flows (m^3/s)								
	1 in 20 (5%)			1 in 100 (1%)			1 in 1000 (0.1%)		
	ReFH	FEH Statistical pooling group	River Leam Hazard Mapping Study FEH Statistical peak	ReFH	FEH Statistical pooling group	River Leam Hazard Mapping Study FEH Statistical peak	ReFH	FEH Statistical pooling group	River Leam Hazard Mapping Study FEH Statistical peak
SWC-CFA16-006	2.76			3.92			6.92		
SWC-CFA16-005	32.48	28.04	31.60	45.05	35.69	53.90	77.48	53.40	107.90
SWC-CFA16-003	5.19			7.43			13.43		
SWC-CFA16-002	5.83			8.37			15.17		

Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	It is vital at this stage that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. Therefore peak flows from the ReFH method have been used in modelling the inflows for the Lower Radbourne north and south viaducts (SWC-CFA16-002 and SWC-CFA16-003) and the Longhole viaduct (SWC-CFA16-006). The 1 in 100 (1%) annual probability event statistical peak flow for the River Itchen viaduct (SWC-CFA16-005) from the River Leam Hazard Mapping Study is higher than the ReFH and FEH Statistical method peak flows calculated for this assessment at this crossing. The crossings of Southam culvert and Ladbroke culvert (SWC-CFA16-004) have small catchments within the larger catchment at the River Itchen viaduct. The ReFH hydrograph for the River Itchen viaduct has been fitted to the peak flow for the River Itchen from the River Leam Hazard Mapping Study. Area weighting has then been used to distribute the hydrograph between the three crossings of the Ladbroke culvert (SWC-CFA16-004), Southam culvert and River Itchen viaduct (SWC-CFA16-005) using the sub-catchment areas (refer to Table 'Distributed peak flows for the River Itchen').

Distributed peak flows for the River Itchen crossings

Site code	Total catchment area (km^2)	Sub-catchment Area (km^2)	1 in 20 (5%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
SWC-CFA16-005 (after sub-catchment redistribution of flow)	77.95	74.45	30.18	61.78	103.06
Southam culvert		1.41	0.57	1.17	1.95
SWC-CFA16-004		2.09	0.85	1.73	2.89

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	None listed for these six catchments.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	This stage of the study requires conservative flow estimates for design purposes and therefore the ReFH method peak flow estimate has been used for three of these catchments with the method generating the highest flows for the remaining three catchments, which was the FEH Statistical method from the River Leam Hazard Mapping Study.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results, however it is considered that the results are conservative and hence would be overestimating, rather than underestimating flows. The catchments to the crossings are un-gauged and where no suitable local donor gauges have been identified, peak flow estimates have been based on catchment descriptors.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been produced for the purposes of the Proposed Scheme initial assessments and should not be used outside of this study except for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase the FEH Statistical method should be carried out for all suitable catchments for comparative purposes and to provide a greater level of confidence with the results. If there is the opportunity to install temporary flow gauges at the un-gauged crossings, this may also improve confidence in design flows at the detailed design phase.

Checks

Are the results consistent, for example at confluences?	N/A separate catchments assessed.
What do the results imply regarding the return periods of floods during the period of record?	N/A
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Range between 1.5 and 1.82.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Different catchments so not comparable.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	Not investigated as part of the initial assessment.
Describe any other checks on the results	None.

Final results

Site code	Flood peak (m^3/s) for the following flood events			
	1 in 20 (5%)	1 in 100 (1%)	1 in 100 (1%) climate change	1 in 1000 (0.1%)
SWC-CFA16-006	2.76	3.92	4.70	6.92
SWC-CFA16-005 (after sub-catchment redistribution of flow)	30.18	53.9	61.78	103.06
Southam culvert	0.57	0.97	1.17	1.95
SWC-CFA16-004	0.85	1.45	1.73	2.89
SWC-CFA16-003	5.19	7.43	8.92	13.43
SWC-CFA16-002	5.83	8.37	10.05	15.17

3.3 Supporting information

River Itchen viaduct (SWC-CFA16-005)

Amendments to default pooling groups

Subject catchment information	
Crossing	River Itchen @ Cr25
NGR	440150, 261500
Catchment area (km^2)	77.95
Permeability	Not permeable (BFIHOST < 0.75 and SPRHOST > 20%)
Urbanisation	Essentially rural (URBEXT2000 < 0.03)
Target return period	100
Required years of data	500

Default pooling group

Name	nYears	L-CV	L-Skew	Discordancy	Distance
37003 (Ter @ Crabbs Bridge)	44.00	0.25	-0.02	0.55	0.25
43017 (West Avon @ Upavon)	38.00	0.24	0.10	0.48	0.32
34012 (Burn @ Burnham Overy)	42.00	0.23	-0.14	0.71	0.33
37014 (Roding @ High Ongar)	45.00	0.25	-0.16	1.54	0.34
34005 (Tud @ Costessey Park)	47.00	0.32	0.26	0.70	0.40
26003 (Foston Beck @ Foston Mill)	48.00	0.25	-0.02	0.17	0.47
33023 (Lea Brook @ Beck Bridge)	44.00	0.42	0.26	2.99	0.48
33032 (Heacham @ Heacham)	40.00	0.32	0.09	1.17	0.49
35004 (Ore @ Beversham Bridge)	42.00	0.26	0.13	0.48	0.49
35003 (Alde @ Farnham)	47.00	0.26	-0.11	1.35	0.50
33063 (Little Ouse @ Knettishall)	28.00	0.26	-0.11	0.42	0.51

Name	nYears	L-CV	L-Skew	Discordancy	Distance
54044 (Tern @ Ternhill)	31.00	0.30	0.29	1.31	0.51
39042 (Leach @ Priory Mill Lechlade)	36.00	0.20	0.01	1.15	0.56
Total	532				
Weighted means		0.27	0.04		

Pooling group review

Comment	Information	Decision	Station years
Discordant sites	33023 (Lea Brook @ Beck Bridge)	Retain – Discordancy alone is not enough reason to remove this station.	532
Period of record (<8 years?)	None		
Assessment of sites flagged on the HiFlows-UK database as 'No Pooling' and No Pooling / No QMED' and sites with permeable catchments or major catchment differences.	43017 (West Avon @ Upavon) Permeable catchment	Retain – remove non-flood years from the record	529
	34012 (Burn @ Burnham Overy) Permeable catchment	Remove – substantially different catchment geology and growth curve.	487
	26003 (Foston Beck @ Foston Mill) Permeable catchment	Retain – remove non-flood years from the record	481
	33023 (Lea Brook @ Beck Bridge) The low flow calibration has been confirmed by current meter. There is some doubt about the high flow calibration owing to two large concrete blocks which spoil the entry condition.	Retain – uncertainty in the rating at high flows but not enough information to remove.	481
	33032 (Heacham @ Heacham)	Remove – substantially different catchment geology and growth curve.	441
	35004 (Ore @ Beversham Bridge) Although CEH rating attempts to account for drowning, station is not good for QMED. Drowning starts below QMED and has significant impact on flows. Rating review suggested.	Retain – although there is some uncertainty in the rating and a review is suggested, catchment similarity is relatively good.	441
	35003 (Alde @ Farnham) Although CEH rating attempts to account for drowning, further investigations are needed. No rating is non modular at high flows and high flows go out of bank.	Retain – uncertainty in the rating at high flows but not enough information to remove.	441
	54044 (Tern @ Ternhill) – No information on rating relationship above b/full stage	Retain – not reason to remove.	441
	39042 (Leach @ Priory Mill Lechlade)	Retain – remove non-flood years from the record	439

Added stations

Name	nYears	L-CV	L-Skew	Discordancy	Distance
36003 (Box @ Polstead)	45.00	0.32	0.12	0.34	0.62
30017 (Witham @ Colsterworth)	30.00	0.28	0.26	1.02	0.62

Reviewed pooling group

Station	Years of data
37003 (Ter @ Crabbs Bridge)	44
43017 (West Avon @ Upavon)	35
37014 (Roding @ High Ongar)	45
34005 (Tud @ Costessey Park)	47
26003 (Foston Beck @ Foston Mill)	42
33023 (Lea Brook @ Beck Bridge)	44
35004 (Ore @ Beversham Bridge)	42
35003 (Alde @ Farnham)	47
33063 (Little Ouse @ Knettishall)	28
54044 (Tern @ Ternhill)	31
39042 (Leach @ Priory Mill Lechlade)	34
36003 (Box @ Polstead)	45
30017 (Witham @ Colsterworth)	30
Total	514

Heterogeneity – following review

3.3.1 The pooling group was found to be strongly heterogeneous. Review of alternative sites indicate it is unlikely the quality of the pooling group will be improved by using stations further down the list generated in WinFap.

Goodness of fit details

Fitting	Z values
Generalised Logistic	3.00
Generalised Extreme Value	-0.23
Pearson Type III	0.08
Generalised Pareto	-6.65
The permeable adjustment method assumes that the flood growth curve follows a Generalised Logistic distribution. On average the Generalised Logistic distribution is considered to perform better than the GEV for pooled growth curve derivation. In this instance the Generalised Logistic distribution has been selected.	

Growth curves

Flood event	Rural (GL)
1 in 2 (50%)	1.000
1 in 10 (10%)	1.669
1 in 20 (5%)	1.931
1 in 50 (2%)	2.291
1 in 75 (1.33%)	2.458
1 in 100 (1%)	2.580
1 in 200 (0.5%)	2.886
1 in 1000 (0.1%)	3.678

Growth curve parameters

Growth curve	Location	Scale	Shape	Bound
Rural GL	1.00	0.27	-0.10	-1.87